Computational Fluid Dynamics Simulation of Dual Bell Nozzle Film Cooling

Kalen Braman*, Christian Garcia**, Joseph Ruf*, and Trong Bui**

*Marshall Space Flight Center, Fluid Dynamics Branch

** Armstrong Flight Research Center, Aerodynamics and Propulsion Branch

Marshall Space Flight Center (MSFC) and Armstrong Flight Research Center (AFRC) are working together to advance the technology readiness level (TRL) of the dual bell nozzle concept. Dual bell nozzles are a form of altitude compensating nozzle that consists of two connecting bell contours. At low altitude the nozzle flows fully in the first, relatively lower area ratio, nozzle. The nozzle flow separates from the wall at the inflection point which joins the two bell contours. This relatively low expansion results in higher nozzle efficiency during the low altitude portion of the launch. As ambient pressure decreases with increasing altitude, the nozzle flow will expand to fill the relatively large area ratio second nozzle. The larger area ratio of the second bell enables higher I_{sp} during the high altitude and vacuum portions of the launch. Despite a long history of theoretical consideration and promise towards improving rocket performance, dual bell nozzles have yet to be developed for practical use and have seen only limited testing. One barrier to use of dual bell nozzles is the lack of control over the nozzle flow transition from the first bell to the second bell during operation. A method that this team is pursuing to enhance the controllability of the nozzle flow transition is manipulation of the film coolant that is injected near the inflection between the two bell contours. Computational fluid dynamics (CFD) analysis is being run to assess the degree of control over nozzle flow transition generated via manipulation of the film injection. A cold flow dual bell nozzle, without film coolant, was tested over a range of simulated altitudes in 2004 in MSFC's nozzle test facility. Both NASA centers have performed a series of simulations of that dual bell to validate their computational models. Those CFD results are compared to the experimental results within this paper. MSFC then proceeded to add film injection to the CFD grid of the dual bell nozzle. A series of nozzle pressure ratios and film coolant flow rates are investigated to determine the effect of the film injection on the nozzle flow transition behavior. The results of this CFD study of a dual bell with film injection are presented in this paper.